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INTERFERENCE WAVE SUPPRESSOR

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INTERFERENCE WAVE SUPPRESSOR

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[There are no amendments to this patent.]

Claims /2*

1. A type of interference wave suppressor characterized by the following facts:

the interference wave suppressor suppresses interference waves with respect to the incident signal wave on an array antenna composed of plural antenna elements set near each other in a prescribed configuration;

the interference wave suppressor has the following means:

a means that converts said incident signal wave into plural digital in-phase/orthogonal signals,

* [Numbers in the right margin indicate pagination of the original foreign language text.]

a means that forms a beam in a prescribed direction from said plural digital in-phase/orthogonal signals, and outputs a first signal corresponding to said beam,

a means that forms multiple beams in different directions simultaneously from said plural digital in-phase/orthogonal signals, and outputs plural second signals corresponding to said multiple beams,

a selection means that selects a prescribed number of signals from said plural second signals based on said first signal and said plural second signals,

a means that multiplies each of said selected signals by a prescribed load coefficient,

a means that adds said signals multiplied by said load coefficient and outputs a third signal,

and a means that subtracts said third signal from said first signal and outputs a fourth signal;

regarding said load coefficient, the initial value is set based on said selected prescribed number of signals and said first signal; then, the load coefficient is controlled by a prescribed adaptive algorithm based on said initial value, said selected prescribed number of signals and said fourth signal such that the power of said fourth signal is at a minimum; and said fourth signal is output as the signal with said interference waves suppressed.

2. The interference wave suppressor described in Claim 1 characterized by the fact that it also has a means for specifying the number of said interference waves based on said first signal and said plural second signals,

and said selection means selects signals in the same number or more than the number of said interference waves from said plural second signals.

3. The interference wave suppressor described in Claim 1 characterized by the following facts: the initial value of said load coefficient is set based on the solution of a set of simultaneous equations based on said first signal and said selected prescribed number of signals for the initially received prescribed number of signal samples; and said adaptive algorithm is an algorithm that refreshes said load coefficient based on the set initial value.

4. The interference wave suppressor described in Claim 3 characterized by the fact that it also has a means for performing singular value decomposition for a prescribed matrix composed of said plural second signals, and it takes the number of singular values as the number of said interference waves.

5. The interference wave suppressor described in Claim 1 characterized by the fact that the initial value of said load coefficient is set based on the solution of a set of simultaneous equations based on said first signal and said selected prescribed number of signals, and said adaptive algorithm is an algorithm that refreshes said load coefficient based on the set initial

value and, at the same time, sets said initial value such that the norm of the initial value vector of the load coefficient is at a minimum.

6. A type of interference wave suppressor characterized by the following facts:

the interference wave suppressor suppresses interference waves with respect to the incident signal wave on an array antenna composed of plural antenna elements set near each other in a prescribed configuration;

the interference wave suppressor has the following means:

a means that converts said incident signal wave into plural digital in-phase/orthogonal signals,

a means that forms a beam in a prescribed direction from said plural digital in-phase/orthogonal signals, and outputs a first signal corresponding to said beam,

a means that uses all or a portion of said plural digital in-phase/orthogonal signals to determine the number of interference waves and their incident directions,

a means that forms beams corresponding to said determined incident directions, respectively, and outputs fifth signals in the same number as that of said beams,

a means that multiplies each of said fifth signals by a prescribed load coefficient,

a means that adds said signals multiplied by said load coefficient and outputs a third signal,

and a means that subtracts said third signal from said first signal and outputs a fourth signal;

regarding said load coefficient, it is controlled according to a prescribed adaptive algorithm to minimize the power of the fourth signal based on said fourth signal and said fifth signals; the initial value of the load coefficient is set based on the solution of a set of simultaneous equations based on said first signal and said fifth signals; said adaptive algorithm is an algorithm that refreshes said load coefficient based on said set initial value, and, at the same time, said initial value is set such that the norm of the initial value vector of the load coefficient is at a minimum.

Detailed explanation of the invention

[0001]

Technical field of the present invention

The present invention pertains to a type of interference wave suppressor. Especially, the present invention pertains to a type of interference wave suppressor that suppresses interference waves incident from the side lobes of an antenna.

[0002]

Prior art

An adaptive array antenna has the zero point oriented in the arrival direction of an interference wave, so that it can effectively remove an interference signal that hampers reception of a desired signal. For an adaptive algorithm used for an adaptive array antenna, it is preferred that the signal processing arithmetic and logic operation quantity be small, and that the load coefficient be converged to the optimum value as soon as possible.

[0003]

In order to realize this objective, for example, in the following reference: Harazawa and Kirimoto: "Increase of converging speed by adjustment of the initial value of the load of beam space ANBF" (1997 Denshi Joho Tsushin Gakkai Sosaietei Daikai [Conference of the Institute /3
of Electronics, Information and Communication Engineers of Japan], B-2-18 (hereinafter to be referred to as Reference 1)), the following scheme is proposed: as represented by an adaptive algorithm, especially the LMS (Least Mean Squares) algorithm, the initial value of the load in the most rapid fall algorithm is set as near the optimum value as possible.

[0004]

Figure 11 is a block diagram illustrating the constitution of an interference wave suppressor of the prior art containing the adaptive array antenna disclosed in said Reference 1. Here, operation of the constitution of the interference wave suppressor in the prior art will be explained with reference to Figure 11.

[0005]

As shown in Figure 11, array antenna (100) is composed of a plurality (N) of element antennas (1-1), (1-2),... (1-N) set near each other. Here, it is assumed that they are set equidistantly and linearly. The RF (Radio Frequency) signals received by said element antennas (1-1), (1-2),... (1-N) (signals as mixtures of the desired signals and interference signals incident in directions different from the desired signals) are amplified and frequency converted by receivers (2-1), (2-2),... (2-N), and they are then converted into digital IF (Intermediate Frequency) signals by A/D converters (3-1), (3-2),... (3-N).

[0006]

Said digital IF signals are converted by IQ signal converters (4-1), (4-1),...(4-N) into base band digital in-phase/orthogonal signals $x_1(k)$, $x_2(k)$,...$x_N(k)$. Here, base band digital in-phase/orthogonal signals $x_1(k)$, $x_2(k)$,...$x_N(k)$ are handled as complex signals with the in-phase

portion of the received RF signals taken as the real portion and the orthogonal signal taken as the imaginary portion. Also, an interference signal is taken as irrelevant to the desired signal.

[0007]

Said base band digital in-phase/orthogonal signals $x_1(k)$, $x_2(k)$,... $x_N(k)$ are input to beam former (5). Said beam former (5) forms a beam in the target direction, and the direction is known. Also, together with the received desired signal, interference signals received at the same time are also input. Here, when the power of the interference signals is much higher than the power of the desired signal, a significant leakage occurs in interference signals incident from the side lobe direction in the orientation characteristics formed by beam former (5). As a result, in addition to the desired signal, output signal $y_0(k)$ also contains an interference signal component that cannot be suppressed by beam former (5) alone.

[0008]

Subtractor (6) subtracts from output signal $y_0(k)$ of beam former (5) signal v(k) estimated as the remaining interference signal not eliminated, and it outputs signal z(k) with the interference signal component suppressed.

[0009]

In the following, an explanation will be given regarding the method for determining the remaining interference signal not eliminated in output signal $y_0(k)$ of beam former (5). Said base band digital in-phase/orthogonal signals $x_1(k)$, $x_2(k)$,... $x_N(k)$ are input to fast Fourier transformer (FFT) (11) that forms multiple beams in plural (N) different directions at the same time. Said multiple beams are auxiliary beams in a side lobe canceller. Then, by means of selector (8), among said plural (N) output signals $y_1(k)$, $y_2(k)$,... $y_N(k)$ of said fast Fourier transformer (11), B output signals with higher power, or B output signals with an output power over certain threshold power, are selected. This corresponds to selection of B beams from the multiple beams formed in plural (N) directions.

[0010]

Many interference signal components are contained in a certain form in said selected signals $y_{r1}(k)$, $y_{r2}(k)$,... $y_{rB}(k)$. After being weighted by multipliers (9-1), (9-2),...(9-B), the selected signals are added by adder (10). The addition result is output as signal v(k) for determining the remainder of the interference signals contained in output signal $y_0(k)$ of beam former (5). Load coefficients $w_1^{(k)}$, $w_2^{(k)}$,... $w_B^{(k)}$ of said multipliers (9-1), (9-2),...(9-B) are controlled by load coefficient controller (22) such that the power of adaptive array antenna

output signal z(k) is reduced as much as possible based on said output signals $y_{r1}(k)$, $y_{r2}(k)$,... $y_{rB}(k)$ of selector (8) and adaptive array antenna output signal z(k). As a result, the remainder of the interference signal contained in output signal $y_0(k)$ of beam former (5) is determined.

[0011]

Control of load coefficients $w_1^{(k)}$, $w_2^{(k)}$,...$w_B^{(k)}$ described in said Reference 1 is performed using a learning identification method, with the refreshing formula of the load coefficients shown as Numeric Formula 1. Here, superscript * indicates the scalar complex conjugate, that is, the complex conjugate of the various elements of the matrix/vector.

[0012]

[Numeric Formula 1]

$$\mathbf{W}^{(k+1)} = \mathbf{W}^{(k)} + \alpha z(k) \frac{\mathbf{Y}^*(k)}{\|\mathbf{Y}(k)\|^2}$$

[0013]

In said Numeric Formula 1, α represents a step size parameter; vectors $W^{(k)}$, Y(k) are vectors defined by the following listed Numeric Formula 2 and Numeric Formula 3, respectively. Here, superscript T indicates transposition of a matrix or vector. Also, other adaptive algorithms may be adopted.

[0014]

[Numeric Formula 2]

$$\mathbf{W}^{(k)} = \left[w_1^{(k)}, w_2^{(k)}, \cdots, w_B^{(k)}\right]^T$$

[0015]

[Numeric Formula 3]

$$\mathbf{Y}(k) = \left[y_{r_1}(k), y_{r_2}(k), \cdots, y_{r_B}(k)\right]^T$$

[0016] /4

As shown in Figure 11, load coefficient initial value vector $W^{(0)}$ set by load coefficient initial value setter (24) is sent to load coefficient controller (22). In load coefficient initial value setter (24), when plural interference waves arrive, the orientation direction of an auxiliary beam is selected under the assumption that they are separated from each other by more than the auxiliary beam width, and where the side lobe level of the auxiliary beam is very low is taken as

the arrival direction of the interference waves. The optimum value is computed when it is assumed that one interference wave arrives in said direction, and the obtained optimum value is taken as the initial value of the load coefficient. This processing is repeated for the number of selected auxiliary beams.

[0017]

For the interference wave suppressor shown in Figure 11, the time to reach convergence is shortened by means of the load refreshing formula of Numeric Formula 1 for said load coefficient initial value vector $W^{(0)}$. Also, here, the precondition is that only one wave is incident in each auxiliary beam.

[0018]

Problems to be solved by the invention

However, for said interference wave suppressor containing an adaptive array antenna in the prior art, when two interference waves near each other arrive and when the auxiliary beam selection number is larger than the received interference wave number, or when the antenna array element number N is small and the auxiliary beam width is wide, or the like, said precondition is not established. As a result, the effect in setting the initial value diminishes, and the time to reach convergence cannot be shortened. This is undesired.

[0019]

The objective of the present invention is to solve the aforementioned problems of the prior art by providing a type of interference wave suppressor characterized by the fact that auxiliary beams in the same number as that of the received interference waves are selected, and the auxiliary beam selection and initial value setting can be performed when two or more interference waves near each other arrive, or when the number of the antenna array elements is small and the auxiliary beam width is wide.

[0020]

Another objective of the present invention is to provide a type of interference wave suppressor characterized by the fact that by selecting auxiliary beams in the same number as that of the received interference waves, it is possible to perform auxiliary beam selection and initial value setting that can be adopted if two or more interference waves near each other arrive and when the number of antenna array elements is small and the auxiliary beam width is wide.

[0021]

Means to solve the problems

In order to realize the aforementioned objectives, the present invention provides a type of interference wave suppressor characterized by the following facts: the interference wave suppressor suppresses interference waves with respect to the incident signal wave on an array antenna composed of plural antenna elements set near each other in a prescribed configuration; the interference wave suppressor has the following means: a means that converts said incident signal wave into plural digital in-phase/orthogonal signals, a means that forms a beam in a prescribed direction from said plural digital in-phase/orthogonal signals, and outputs a first signal corresponding to said beam, a means that forms multiple beams in different directions simultaneously from said plural digital in-phase/orthogonal signals and outputs plural second signals corresponding to said multiple beams, a selection means that selects a prescribed number of signals from said plural second signals based on said first signal and said plural second signals, a means that multiplies each of said selected signals by a prescribed load coefficient, a means that adds said signals multiplied by said load coefficient and outputs a third signal, and a means that subtracts said third signal from said first signal and outputs a fourth signal; regarding said load coefficient, the initial value is set based on said selected prescribed number of signals and said first signal; then, the load coefficient is controlled by a prescribed adaptive algorithm based on said initial value, said selected prescribed number of signals and said fourth signal such that the power of said fourth signal is at a minimum; and said fourth signal is output as the signal with said interference waves suppressed.

[0022]

As a preferable scheme, according to the present invention, it also has a means for specifying the number of said interference waves based on said first signal and said plural second signals, and said selection means selects signals in the same number or more than the number of said interference waves from said plural second signals.

[0023]

As a preferable scheme, according to the present invention, the initial value of said load coefficient is set based on the solution of a set of simultaneous equations based on said first signal and said selected prescribed number of signals for the initially received prescribed number of signal samples; and said adaptive algorithm is an algorithm that refreshes said load coefficient based on the set initial value.

[0024]

As another preferable scheme, according to the present invention, it also has a means for performing singular value decomposition for a prescribed matrix composed of said plural second signals, and it takes the number of singular values as the number of said interference waves. In addition, the initial value of said load coefficient is set based on the solution of the set of simultaneous equations based on said first signal and said selected prescribed number of signals, and said adaptive algorithm is an algorithm that refreshes said load coefficient based on the set initial value and, at the same time, sets said initial value such that the norm of the initial value vector of the load coefficient is at a minimum.

[0025]

As a preferable scheme, the present invention provides a type of interference wave suppressor characterized by the following facts: the interference wave suppressor suppresses interference waves with respect to the incident signal wave on an array antenna composed of plural antenna elements set near each other in a prescribed configuration; the interference wave suppressor has the following means: a means that converts said incident signal wave into plural digital in-phase/orthogonal signals, a means that forms a beam in a prescribed direction from said plural digital in-phase/orthogonal signals, and outputs a first signal corresponding to said beam, a means that uses all or a portion of said plural digital in-phase/orthogonal signals to determine the number of interference waves and their incident directions, a means that forms beams corresponding to said determined incident directions, respectively, and outputs fifth signals in the same number as that of said beams, a means that multiplies each of said fifth signals by a prescribed load coefficient, a means that adds said signals multiplied by said load coefficient and outputs a third signal, and a means that subtracts said third signal from said first signal and outputs a fourth signal; regarding said load coefficient, it is controlled according to a /5
prescribed adaptive algorithm to minimize the power of the fourth signal based on said fourth signal and said fifth signals; the initial value of the load coefficient is set based on the solution of a set of simultaneous equations based on said first signal and said fifth signals; said adaptive algorithm is an algorithm that refreshes said load coefficient based on said set initial value, and, at the same time, said initial value is set such that the norm of the initial value vector of the load coefficient is at a minimum.

[0026]

Embodiment of the present invention

In the following, an explanation will be given regarding embodiments of the present invention with reference to annexed figures.

Embodiment 1

Figure 1 is a block diagram illustrating the constitution of the interference wave suppressor in Embodiment 1 of the present invention. For the device shown in Figure 1, the same part numbers as those adopted in Figure 11 for the interference wave suppressor of the prior art are adopted, so they will not be explained again. Also, in the present embodiment, a linear configuration is not necessary in setting the antenna elements. In the following explanation, if not specified otherwise, n=1, 2,... N, i=1, 2,...I, and b=1, 2,...B.

[0027]

In the interference wave suppressor shown in Figure 1, base band digital in-phase/orthogonal signals $x_n(k)$ are input to beam former (5) for extracting desired signals. At the same time, they are also input to multi-beam former (7) that forms plurality (I) of beams in direction directions. Here, the multiple beams are auxiliary beams in a side lobe canceller.

[0028]

As an example of said multi-beam former (7), there is said fast Fourier transformer. In this case, number I of the multiple beams is equal to element number N. Based on output signals $y_i(k)$ of multi-beam former (7) and output signal $y_0(k)$ of beam former (5), which signal to be selected from among output signals $y_1(k)$, $y_2(k)$,... $y_I(k)$ is determined, in other words, which direction of the beam to be selected from among the multiple beams formed by multi-beam former (7) is determined, and the selected beam number is output to selector (8).

[0029]

Said selector (8) selects the beams in a direction determined by said selected beam setter (21), that is, it selects the corresponding multi-beam output signal. The selection number is taken as B. The selection procedure will be explained later. Here, selection of auxiliary beams in the appropriate direction equal to the interference wave number by selector (8) will be explained.

[0030]

Assume that the signals selected by selector (8) are signals $y_{r1}(k)$, $y_{r2}(k)$,... $y_{rB}(k)$. That is, after the selected signals (hereinafter to be referred to as $y_{rb}(k)$ for convenience) are weighted by multiplier (9-b) (one of multipliers (9-1), (9-2),...(9-B) corresponding to signal $y_{rb}(k)$), they are summed by adder (10). Said adder (10) outputs signal v(k) for determining the remainder of the interference signal contained in output signal $y_0(k)$ of beam former (5).

[0031]

Load coefficient $w_b(k)$ of said multiplier (9-b) is controlled by load coefficient controller (22) based on signal $y_{rb}(k)$ of selector (8) and adaptive array antenna output signal z(k) such that the power of said adaptive array antenna output signal z(k) is as soon as possible. As a result, the remainder of the interference signal contained in output signal $y_0(k)$ of beam former (5) is determined. Then, by means of subtractor (6), determined remainder v(k) of the interference signal is subtracted from output signal $y_0(k)$ of beam former (5) so as to suppress the interference signal.

[0032]

The method for controlling the load coefficient by load coefficient controller (22) is the same as that in the device of the prior art shown in Figure 11. However, one may also adopt a control method other than the learning identification method. Yet load coefficient initial value $w_b^{(0)}$ is different from the load coefficient initial value in the prior art (that is, load coefficient initial value setter (23a) pertaining to the present embodiment sets the load coefficient initial value using a method different from that of load coefficient initial value setter (24) shown in Figure 11). Here, the procedure will be explained for setting the load coefficient initial value vector in load coefficient initial value setter (23a) by means of selected beam setter (21a), with selection performed by selector (8) for the auxiliary beams with number equal to the interference wave number and in the appropriate direction.

[0033]

In the present embodiment, a correlated matrix is formed using the initially received signal samples in a very small number of output signal $y_0(k)$ of beam former (5) and signal $y_{rb}(k)$ of selector (8). The normal equation is solved as is, and the result is taken as the initial value vector of the adaptive algorithm. That is, the load coefficient initial value $w_b^{(0)}$ is determined using the SMI (Sample Matrix Inversion) method by means of the initially received small number of samples. Here, there is no need to adopt the assumption in said Reference 1 that "only one interference wave is incident in each auxiliary beam (there exists only one interference signal exists in each auxiliary beam output)," that is, only one interference wave is taken as incident, and the load is not determined. Consequently, even if two or more interference waves near each other are incident, it is still possible to set the initial value near the optimum value.

[0034]

Here, assuming that the signal sample number for setting the load initial value is P, load coefficient initial value vector $W^{(0)}$ can be determined using the following formulas. In Numeric

Formulas 5 and 6, $[C]_{ij}$ refers to the (i, j) element of matrix C, and $[r]_j$ refers to the jth element of vector r. Also, i, j=1, 2, … B.

[0035]
[Numeric Formula 4]

$$\mathbf{w}^{(0)} = \mathbf{C}^{-1}\mathbf{r}$$

[0036]
[Numeric Formula 5] /6

$$[\mathbf{C}]_{ij} = \sum_{k=0}^{P-1} y_{r_i}^{*}(k)\, y_{r_j}(k)$$

[0037]
[Numeric Formula 6]

$$[\mathbf{r}]_j = \sum_{k=0}^{P-1} y_{r_j}^{*}(k)\, y_0(k)$$

[0038]

In practice, it is preferred that instead of directly solving a normal equation with poor numeric properties, the solution be derived by means of QR decomposition from the data matrix. For this purpose, following matrix A and vector a are formed from the output signal of beam former (5) and selector (8).

[0039]
[Numeric Formula 7]

$$\mathbf{A} = \begin{bmatrix} y_{r_1}(0) & y_{r_2}(0) & \cdots & y_{r_B}(0) \\ y_{r_1}(1) & y_{r_2}(1) & \cdots & y_{r_B}(1) \\ \vdots & \vdots & & \vdots \\ y_{r_1}(P-1) & y_{r_2}(P-1) & \cdots & y_{r_B}(P-1) \end{bmatrix}$$

[0040]
[Numeric Formula 8]

$$\mathbf{a} = [y_0(0), y_0(1), \cdots, y_0(P-1)]^T$$

[0041]

Then, as shown in Numeric Formula 9, QR decomposition is performed for matrix A.

[0042]
[Numeric Formula 9]

$$A=QR$$

[0043]
Here, Q represents a PXB matrix with the columns becoming a normal orthogonal system, and R represents the upper-right triangular matrix of BXB. By means of Q, R, the normal equation becomes the following listed Numeric Formula 10. Since R is the upper-right triangular matrix, Numeric Formula 10 can be solved simply by means of retreating substitution. In Numeric Formula 10, superscript H indicates conjugated transposition of the matrix/vector.

[0044]
[Numeric Formula 10]

$$RW^{(0)}=Q^{H}B$$

[0045]
Said load coefficient initial value vector $W^{(0)}$ determined in the above is sent to load coefficient controller (22). Based on it, refreshing of the load coefficient is started. In this way, by setting load coefficient initial value $w_b^{(0)}$, different from the setting method of the load coefficient initial value described in said Reference 1, an effect in setting the initial value can be displayed in almost all cases. That is, in almost all cases, convergence can be realized in a short time.

[0046]
In the following, an explanation will be given regarding the operation of selected beam setter (21a), that is, selection of a signal by selector (8) (selection procedure of auxiliary beams). Figures 2 and 3 are flow charts illustrating the procedure of setting of a selected auxiliary beam by selected beam setter (21a).

[0047]

(Step A1)

For the initial P samples of the received signals needed for setting the initial value, the distribution in the spatial direction of the average power of output signals $y_1(k)$, $y_2(k)$,... $y_I(k)$ of multi-beam former (7) is determined, and the peak (maximum value) is extracted (SSA1-1). In SSA1-2, when number M of the maximum values is judged to be 1, the flow goes to Step A2. When number M of the maximum values is 2 or larger, the flow branches to Step A5 shown in Figure 3.

[0048]

(Step A2)

As explained above, when number M of the maximum values is 1, near the beam direction that gives the maximum value, the priority order of the auxiliary beams is set in the order of electric power. Here, it is assumed that the number of selected auxiliary beams is taken as a little larger than the assumed interference wave number (about 3 in practice). Also, in this case, the maximum selected beam number is taken as β.

[0049]

(Step A3)

At first, when the auxiliary beams are not selected, from time k=0 to k=P-1, the adaptive array antenna output signal power is determined (SSA3-1, SSA3-4). Then, according to the priority order determined in Step A2, the auxiliary beam selection number is increased by 1 (SSA3-5), and, according to the setting procedure in said load coefficient initial value setter (23a) (that is, by means of Numeric Formulas 8-10), the load coefficient value is computed for each auxiliary beam selection number (that selected in SSA3-2). Then, from time k=0 to k=P-1, adaptive array antenna output signal power $P_z(d)$ is determined (SSA3-4).

[0050]

As shown in SSA3-2, assuming that d beams are selected, the beam number is taken as $\{q_1, q_2, \ldots q_d\}$, and the load coefficient values in this case are $w_{\sim 1}$, $w_{\sim 2}$,... $w_{\sim d}$, adaptive array antenna output signal power $P_z(d)$ can be computed using following listed Numeric Formulas 11 and 12. In Numeric Formula 12, d=0 corresponds to the case when none of the beams is selected.

[0051]
[Numeric Formula 11]

$$z(k) = y_0(k) - \sum_{n=1}^{d} \bar{w}_n y_{q_n}(k) \qquad k = 0, 1, \cdots, P-1$$

[0052]
[Numeric Formula 12]

$$P_z(d) = \frac{1}{P} \sum_{k=0}^{P-1} |z(k)|^2 \qquad d = 0, 1, 2, \cdots, \beta$$

[0053]
(Step A4)

In SSA3-6, when it is judged that selected beam number d exceeds maximum selected beam number β, processing is shifted to this step. In this step, for d=0, 1, 2, … β, from variation /7 in the value of $P_z(d)$ determined using Numeric Formula 12, the beam to be selected is determined. That is, when the selected beam number is insufficient, there is little change in $P_z(d)$. When the selected beam number is in agreement with the interference wave incident number, compared with the case when the beam number is insufficient, $P_z(d)$ decreases drastically. Then, as the selected beam number rises above the interference wave incident number, there is little change in $P_z(d)$. Based on this, the selected beam is determined.

[0054]

When the number of the maximum value of the distribution in the spatial direction of the auxiliary beam output signal power is 1, after said Step A4, the procedure of selection of the auxiliary beams comes to an end. When the number of said maximum value is 1, load coefficient initial value $w_b^{(0)}$ is determined simultaneously, and it is used as the initial value in load coefficient controller (22). That is, in this case, there is no need to re-determine the initial value by load coefficient initial value setter (23a).

[0055]
(Step A5)

When the number of the maximum value M ≥ 2, the formal processing step shown in Figure 3 is entered. Here, near the beam direction that provides the maximum values, the priority order of the auxiliary beams is applied in the order of electric power. Here, the number of auxiliary beams selected near the various maximum points (beam directions that give the maximum values) is a little larger than the number of incident interference waves assumed near

the angles, and it is about 3 in practice. Also, in this case, the maximum selected beam number near the various maximum points is taken as β_m. Here, m=1, 2,... M.

[0056]

(Step A6)

In this step, at first, for the state in which no beam is selected, just as in said Step A3, the adaptive array antenna output signal power is determined. Then, one maximum point (with number m) (SSA6-1) is considered. Near the other maximum points (excluding m), for the beams determined in Step A5, all of the auxiliary beams are selected. Here, near the maximum point where the beam to be selected is determined, the beam is selected (SSA6-3).

[0057]

Then, near number m, the selected beams are increased one by one (SSA6-6, SSA6-7). In each case, according to said Numeric Formulas 7-10, the load coefficient value for each auxiliary beam selection number is computed (SSA6-4). Then, from time k=0 to k=P-1, adaptive array antenna output signal power $P_z^m(d)$ is determined (SSA6-5). Here, d corresponds to the state that for the beams near maximum point number m, d of them are selected, and, for the beams near the other maximum points, all are selected. Here, d=0 indicates the state wherein no beam is selected. Here, superscript m of $P_z^m(d)$ indicates that the vicinity of maximum point number m is considered.

[0058]

(Step A7)

Here, from the values of $P_z^m(0)$, $P_z^m(1)$, ... $P_z^m(\beta_m)$, the selected beam at maximum value number m is determined (SSA7-1). The scheme for determination is the same as that in said Step A4. Then, the value in SSA7-2 is increased by 1. The operation of Step A6 and Step A7 is repeated for M rounds as the number of maximum values in the spatial distribution (SSA7-3).

[0059]

(Step A8)

As the operation of Step A6, Step A7 is repeated for the number of maximum values in the spatial distribution, the beams to be selected near the maximum points are determined, respectively. Then, they are all collected to become to become the overall auxiliary beams to be selected. With said processing, the operation for selecting the auxiliary beams comes to an end.

[0060]

In this way, here, the signal processing arithmetic and logic operation quantity needed for each round of refreshing of the load coefficient is smaller, and, by performing interference wave suppression using an adaptive algorithm based on the fastest falling method, the initial value of the load near the optimum value corresponding to the incident direction is set to be the same as the number of received interference waves.

[0061]

As explained above, according to the present embodiment, by selecting the auxiliary beams in the appropriate beam directions in the same number as the received interference waves, and by using the initial small number of the received signal samples to set the load coefficient initial value using the SMI method, even if two or more interference waves near each other are incident, it is still possible to set the initial value near the optimum value. As a result, it is possible for the load coefficient to reach the optimum value at high speed. That is, by selecting the auxiliary beams that display interference wave suppressing characteristics in a short time, it is possible to select the appropriate auxiliary beams in the same number as the interference waves, and it is possible to set the load coefficient initial value near the optimum value.

[0062]

Embodiment 2

In the following, an explanation will be given regarding the procedure for selecting auxiliary beams pertaining to Embodiment 2 of the present invention. The constitution of the interference wave suppressor pertaining to the present embodiment is identical to the device pertaining to said Embodiment 1 as shown in Figure 1. Consequently, the constitution will not be explained again. Here, however, the output signal of beam former (5) is not used.

[0063]

Figures 4 and 5 are flow charts illustrating the procedure for setting the selected auxiliary beams by means of selected beam setter (21a) in the present embodiment.

(Step B1)

At first, the distribution in the spatial direction of the average power of output signals $y_1(k)$, $y_2(k)$,... $y_I(k)$ of multi-beam former (7) with respect to the initial P samples of the received signal needed for setting the initial value is determined, and its peak (maximum value) is extracted. When number M of the maximum values is 1, the flow goes to Step B2. On the other hand, when number M of the maximum values is 2 or larger, the flow branches to Step B5 in

Figure 5. This operation is the same as that in Step A1 (Figure 2) within the procedure of selection of the auxiliary beams in said Embodiment 1.

[0064]

(Step B2)

When number of maximum values M is M=1, near the beam direction that gives the maximum value, the priority order of the auxiliary beams is set in the order of electric power. Here, the number of selected auxiliary beams is taken as a little larger than the assumed interference wave number, and it is about 2-3 in practice depending on the auxiliary beam width. Also, in this case, the selected beam number is taken as β.

[0065] /8

(Step B3)

Matrix A of said Numeric Formula 7 is formed with respect to the selected beam output signal. Here, in Numeric Formula 7, it is assumed that B=β. As shown in following Numeric Formula 13, singular value decomposition is performed for matrix A.

[0066]

[Numeric Formula 13]

$$A = USV^H$$

[0067]

Here, U represents a P x β matrix with its column vectors in a normal orthogonal state; S represents a β x β diagonal matrix; and V represents a β x β orthogonal matrix.

[0068]

The diagonal elements of matrix S are the singular values of matrix A. The number of non-zero singular values is the rank of matrix A. The correlated matrix made of the output signals of selector (8) gives $A^H A$. Its rank is equal to the number of interference waves when noise is not present. It is equal to the rank of A. That is, the number of non-zero singular values of matrix A is the incident number of interference waves. In practice, due to presence of noise of the receiver, the singular values do not become zero. However, when the interference wave power is much higher than the noise power, a significant difference occurs in the order of the singular values. Consequently, in this case, small singular values are ignored, while the number of large singular values is judged as the number of interference waves.

[0069]

(Step B4)

In this step, from among the β beams selected in said Step B2, the beams with the number of interference waves judged in Step B3 are selected in priority order. That is, from the singular values of matrix A, the number of interference waves is judged, and auxiliary beams in the number of said interference waves in said priority order are selected, and this operation for selecting beams comes to an end.

[0070]

(Step B5)

On the other hand, when the number of maximum values M is $M \geq 2$, as shown in Figure 5, in this step, near the beam direction that gives the maximum value, the priority order of the auxiliary beams is attached in the order of power. Here, the number of selected auxiliary beams is taken as a little larger than the assumed interference wave number incident near the angle, and it is about 2-3 in practice. Also, in this case, the selected beam number is taken as β_m near each maximum point. Also, here, m=1, 2,... M.

[0071]

(Step B6)

One maximum point (number m) is considered, and, for the signals selected near its maximum point, the same operation as in said Steps B3 and B4 is performed. However, here, in SSB6-2 corresponding to Step B3, β_m is used instead of β. That is, from the singular values of matrix A, the interference wave number is judged, and auxiliary beams in the number of said interference waves in said priority order are selected. As a result, near the maximum point m, the auxiliary beams to be selected are determined (SSB6-3). Then, in SSB6-4, the value of m is increased by 1, and then, in SSB6-5, said operation is repeated at each maximum point until it is judged that m is over M (that is, the operation is repeated for a total of M rounds).

[0072]

(Step B7)

The selected beams determined near the various maximum points are collected to determine the auxiliary beams to be selected, and the present processing comes to an end.

[0073]

As explained above, in the present embodiment, beams in the number of the interference waves are selected, that is, the interference wave number is judged from the results obtained by singular value decomposition of the prescribed matrix, and auxiliary beams are selected for the number of interference waves in priority order. As a result, it is possible to select appropriate auxiliary beams in the same number as that of the interference waves, and it is possible to set the load coefficient initial value near the optimum value.

[0074]

In said Embodiment 2, for matrix A of Numeric Formula 7 (where, $B=\beta$, or $B=\beta_m$), singular value decomposition is performed. However, the present invention is not limited to this scheme. That is, one may also adopt a scheme in which the eigenvalues are computed for correlation matrix $A^H A$, and, instead of the singular values in Embodiment 2, the eigenvalues of $A^H A$ are used to determine the selected beams. Also, in this case, since the eigenvalues of $A^H A$ are equal to the square of the singular value of A, the judgment standard of the interference wave number may be equal to that in Embodiment 2.

[0075]

Embodiment 3

In the following, an explanation will be given regarding Embodiment 3 of the present invention. Figure 6 is a block diagram illustrating the constitution of the interference wave suppressor in the present embodiment. The device shown in said figure is the same as the device in Embodiment 1 shown in Figure 1, except for selected beam setter (21b) and load coefficient initial value setter (23b). Here, explanation of the operation of the elements with the same constitution as aforementioned will not be repeated. Consequently, in the following, an explanation will be given regarding mainly the operation of selected beam setter (21b) and load coefficient initial value setter (23b).

[0076]

Said selected beam setter (21b) shown in Figure 6 (its operation is for selecting the signal in selector (8) (selection procedure of multiple beams as auxiliary beams)) is set such that the number of auxiliary beams is equal to or larger than the number of interference waves near the interference wave incident direction. This is simpler than the procedure of setting in selected beam setter (21a) in the devices in said Embodiments 1 and 2.

[0077]

For the initial P samples (or fewer samples) of the received signal needed for initial value setting, selected beam setter (21b) determines the distribution in the spatial distribution of the average power of output signals $y_1(k)$, $y_2(k)$,... $y_I(k)$ of multi-beam former (7), and extracts the peaks (maximum values). Near each maximum value, auxiliary beams in a number equal to or a little larger than the number of interference waves assumed to be incident from near the beam direction are selected, and the procedure comes to an end.

[0078]

In the following, an explanation will be given regarding the operation of load coefficient initial value setter (23b). Said load coefficient initial value setter (23b) computes load coefficient initial value vector $W^{(0)}$ using the well known singular value decomposition method such that for matrix A shown in Numeric Formula 7 and vector a shown in Numeric Formula 8 comprised of the output signal of beam former (5) and the output signal of selector (8), the value represented by Numeric Formula 14 is the smallest, and its own square norm value becomes the smallest, and it takes the result as the load coefficient initial value.

[0079] /9

[Numeric Formula 14]

$$\|AW^{(0)} - a\|^2$$

[0080]

The specific procedure is as follows. That is, matrix A is subjected to singular value decomposition as shown in Numeric Formula 15.

[0081]

[Numeric Formula 15]

$$A = USV^H$$

[0082]

Here, U represents a P x B matrix with its column vectors in a normal orthogonal state; S represents a B x B diagonal matrix; and V represents a B x B orthogonal matrix.

[0083]

The diagonal elements of matrix S are the singular values of matrix A. The number of non-zero singular values is the rank of matrix A. The correlated matrix made of the output signals of selector (8) shown in Figure 6 gives $A^H A$. Its rank is equal to the number of interference waves when there noise is not present. It is equal to the rank of A. That is, the number of non-zero singular values of matrix A is the incident number of interference waves. In practice, due to the presence of noise of the receiver, the singular values do not become zero. However, when the interference wave power is much higher than the noise power, a significant difference occurs in the order of the singular values. Consequently, in this case, small singular values are ignored, while the number of large singular values is judged as the number of interference waves.

[0084]

The size indicated by following Numeric Formula 16 is for computing vector α of Bx1. Also, as shown in Numeric Formula 17, vector c is defined. At this time, vector c is unknown.

[0085]

[Numeric Formula 16]

$$\alpha = U^H a$$

[0086]

[Numeric Formula 17]

$$c = V^H W^{(0)}$$

[0087]

Bx1 vector c of said Numeric Formula 17 is prepared in the following procedure. That is, when the value of $[S]_{bb}$ cannot be ignored with respect to the singular values in the larger order, one has $[c]_b = [\alpha]_b / [S]_{bb}$, and when it can be ignored, one has $[c]_b = 0$. In this way, vector c becomes approximately the least square minimum norm solution of the set of simultaneous equations $Sc=\alpha$.

[0088]

As explained above, since matrix V is orthogonal, by means of Numeric Formula 17, it is possible to determine the desired load coefficient initial value vector $W^{(0)}$ from matrix V and

vector c using Numeric Formula 18. Here, it is output as the load initial value to load coefficient controller (22).

[0089]

[Numeric Formula 18]

$$W^{(0)} = Vc$$

[0090]

As explained above, according to the present embodiment, the selected beam setter is set such that the number of auxiliary beams is identical to or larger than the number of interference waves near the interference incident direction, and, by means of the load coefficient initial value setter, the load vector is computed using the singular value decomposition method. As a result, even if the number of signals selected by the selector is larger than the number of interference waves, it is still possible to determine the load coefficient initial value near the optimum value, and it is possible to have load coefficient $w_b^{(k)}$ converge to the optimum value at high speed.

[0091]

Embodiment 4

In the following, an explanation will be given regarding Embodiment 4 of the present invention. Figure 7 is a block diagram illustrating the constitution of the interference wave suppressor in this embodiment. The same part numbers as those adopted in Embodiment 3 shown in Figure 6 are adopted here, and they will not be explained again.

[0092]

The interference wave suppressor shown in Figure 7 has interference wave incident direction determining unit (30) that determines the interference wave incident number (assumed to be B here) and the direction using all or a portion of base band digital in-phase/orthogonal signals $x_n(k)$, with n=1, 2,.....N, and auxiliary beam formers (31-b) (b=1, 2,... B) that form beams in the interference wave incident direction based on the interference wave number and incident direction determination results obtained by said interference wave incident direction determining unit (30). For example, in order to determine the interference wave number and incident direction, one may adopt the spatial direction FFT, the maximum entropy method, the MUSIC (Multiple Signal Classification) method, etc. described in the following reference: Brookner and Howell:

「Adaptiv|e-adaptivearray processing」

(April 1986, Proceedings of the IEEE, Vol. 74, No. 4, pp. 602-604).

[0093]

Assume that the outputs of auxiliary beam formers (31-b) are output signals $y_1(k)$, $y_2(k)$,... $y_B(k)$. Here, by means of an algorithm just as in said adaptive algorithm, load coefficients $w_1^{(k)}$, $w_2^{(k)}$,... $w_B^{(k)}$ are controlled. As a result, interference waves are suppressed. Here, the adaptive algorithm is not limited to said learning identification method. The procedure for setting load coefficient initial value $w_b^{(0)}$ is the same as that in said Embodiment 3. For Numeric Formula 7, $y_{rb}(k)$ is replaced by output signal $y_b(k)$ (b=1, 2,... B) of auxiliary beam formers (31-b). It should be pointed out here that even if the method for setting the load coefficient initial value vector described in said Reference 1 is adopted in the present embodiment, when plural interference waves are near each other, there is no effect in setting the initial value, and quick convergence cannot be obtained.

[0094]

In this way, according to the present embodiment, by determining the interference wave number and incident direction and by forming beams in the interference wave incident direction based on the results, even if plural interference waves exist near each other, and if other interference waves leak to certain auxiliary beams, load coefficient convergence at high speed is still possible.

[0095]

Application examples

In the following, an explanation will be given regarding application examples pertaining /10
to said Embodiments 1-3. Here, by means of computer simulation, the effectiveness of the interference wave suppressor in said embodiments will be shown.

Application Example 1

The following is an application example corresponding to said Embodiment 1. Here, an array antenna composed of 64 elements set in a linear configuration with half-wavelength mutual spacing is assumed. The desired wave (with signal-to-noise ratio SNR=5 dB for each element) is incident from the normal direction ($\theta=0°$) of the array antenna. Said beam former (5) orients a beam at $\theta=0°$. Also, three interference waves are incident at directions of $\theta=10°$ (interference-to-noise power ratio INR=45 dB for each element), $\theta=12°$ (INR=35 dB for each element), and $\theta=-25°$ (INR=40 dB for each element). In formation of the multiple beams

(auxiliary beams), fast Fourier transformation is adopted, and a Hanning window is formed before performing said fast Fourier transformation.

[0096]

First of all, the auxiliary beams to be selected are determined. According to said Step A1 (Figure 2), the distribution of the output signal average power of multi-beam former (7) is determined. Figure 8 is a diagram illustrating the distribution. In this figure, for the beam number of the abscissa, the beam in the direction of 0° is taken as No. 1 (hereinafter to be referred to as #1), and the beam number is increased towards the right up to $\theta=90°$ as viewed from the array antenna. At $\theta=\pm 90°$, the number is taken as #33. With this as the boundary, the beam number rises as the position moves from $\theta=-90°$ towards the front surface. The #64 beam is the beam in the direction at about -2°. For the distribution shown in Figure 8, as the signal samples, the initial 10 samples (P=10) are used. Also, in Figure 8, since there are maximums at two sites (M=2), processing goes to Step A5 shown in Figure 3.

[0097]

According to Step A5, near the maximum points shown in Figure 8, priority ordering is applied on the auxiliary beams in the order of electric power. That is, near #7, the priority order is applied as #7, #6, #8 ($\beta_1=3$), and, near #51, the priority order is applied in the order of #51, #52, #50 ($\beta_2=3$).

[0098]

According to Step A6, when no beam is selected, the adaptive array antenna output signal power is determined. Then, the vicinity of #7 maximum point is considered. Also, all of #51, #52, #50 near the other maximum point #51 are selected, and the selected beams are increased in the order of #7, #6, #8. In each case, the load coefficient is determined, and the adaptive array antenna output signal power is determined. That is, the load coefficient is determined in the three cases when the selected beams are (#51, #52, #50, #7), (#51, #52, #50, #7, #6), and (#51, #52, #50, #7, #6, #8), and the adaptive array antenna output signal power is determined.

[0099]

When the aforementioned electric power values are described, they can be set sequentially from the state when none is selected: 117、6　20、93　2. 30　1. 39 .
Except for #51, #52, #50, when #7 and #6 beams are selected, the electric power decreases significantly (20.93 → 2.30). After that, the decrease in electric power becomes smaller. As a

result, in Step A7 (Step A4), the beams that should be selected near #7 are judged to be #7 and #6.

[0100]

Then, the vicinity of maximum point #51 is considered. The determined beams #7 and #6 are selected, the selected beams are increased in the order of #51, #52, #50, and the load coefficient is determined for each case. As a result, the adaptive array antenna output signal power is determined. That is, after determining the load coefficients in the three cases of selected beams (#7, #6, #51), (#7, #6, #51, #52), (#7, #6, #51, #52, #50), the adaptive array antenna output signal power is determined. Also, the power in the state wherein no beam is selected has been determined as explained above.

[0101]

Here, the aforementioned power values can be listed sequentially from the state when none is selected:
117.6 3.30 2.67 2.30 |. Except for #7 and #6, when #51 is selected, the power falls significantly, and the decrease in power then becomes smaller after that. As a result, the beam to be selected near #52 is judged as #51.

[0102]

In the aforementioned process, three auxiliary beams should be selected, namely, #7, #6, #51. As a result, the selected auxiliary beams are taken as #7, #6, #51, and the load coefficient initial value is computed again using Numeric Formulas 7-10. The result is taken as the initial value, and the load coefficient is refreshed using the learning identification method of Numeric Formula 1. In Numeric Formula 1, one has α=0.2. In this case, Figure 9 shows a degree of improvement (improvement factor in units of dB) in the signal-to-noise ratio for the interference signal versus the number of rounds of refreshing of the load coefficient. Also, Figure 9 shows the convergence characteristics when the method described in Reference 1 is used and the load coefficient initial value is taken as the 0 vector. In both cases, the selected auxiliary beams are the same three auxiliary beams, that is, #7, #6, #51.

[0103]

Because the initial 10 samples are used in setting the initial value of the load, in the method pertaining to the present application example and the method described in Reference 1, the load coefficient value is taken as the 0 vector. In the procedure for setting the load coefficient initial value in the present application example, the operation does not come to an end until input

of the next sample, and it is estimated that a time for more than ten samples is needed. However, even when this factor is taken into consideration, as shown in Figure 9, the load coefficient still can converge in a very short time. Also, for the method described in Reference 1, when the interference waves are near each other in incidence and the precondition that one interference wave is incident in each auxiliary beam cannot be met, it becomes impossible to shorten the time for reaching convergence by setting the load coefficient initial value.

[0104]

Application Example 2

In this application example, the selection of the auxiliary beams pertaining to said Embodiment 2 will be shown. Here, the conditions are the same as those in Application Example 1. That is, in Step B1 (Figure 4), within the procedure of selection of the auxiliary beams pertaining to Embodiment 1, the state is the same as that in Step A1. Then, as shown in Figure 8, because the maximum values occur at two sites, processing goes to Step B5 shown in Figure 5. /11

[0105]

Here, in Step B5, priority ordering is applied on the auxiliary beams in the order of electric power near each maximum point shown in Figure 8. Near #7, three are selected and the priority order is applied as #7, #6, #8 (β_1=3) and, near #51, two are selected and the priority order is applied in the order of #51, #52 (β_2=2). Here, for #53, since the electric power is low, it is not selected.

[0106]

Then, in Step B6, the vicinity of the maximum point located on the left in Figure 8 (near #7) is considered. While #7, #6, #8 are selected, matrix A of Numeric Formula 7 is formed. Here, one has $B = \beta_1 = 3$. Then, for matrix A, singular value decomposition is performed. As a result, the singular values of matrix A become the following listed in falling order.

351.9 82.20 0.0654

[0107]

Among the obtained singular values, the third singular value is much smaller than the remaining two. As a result, it can be neglected in the judgment, and it is judged that two interference waves are incident near #7. Consequently, among #7, #6, #8, the two beams with higher power, that is, #7 and #6, are selected.

[0108]

Then, the vicinity of the maximum point located on the right in Figure 8 (#51) is considered. That is, #51 and #52 are selected to form matrix A of Numeric Formula 7. Here, one has $B=\beta_2=2$. Then, for matrix A, singular value decomposition is performed. As a result, the singular values of matrix A become the following listed in falling order.

191.8 0.140 |

[0109]

For the above-listed two singular values, there is a significant difference in the magnitude between them. Consequently, it is judged that the second singular value can be neglected, and it is judged that only one interference wave is incident near #51. Consequently, from among #51, #52, one beam with the higher power, that is, #51, is selected.

[0110]

As explained above, according to the present invention, the selected beams are #7, #6, #51. Since the same selection results as that in Application Example 1 are obtained, the converging characteristics are the same as those shown in Figure 9 (in the figure, these characteristics are denoted as "Application Examples 1, 2").

[0111]

Application Example 3

In this application example, in the same electromagnetic wave environment as that in Application Example 1, the same multiple beams are formed, and computer simulation is performed to show the effectiveness of the interference wave suppressor pertaining to said Embodiment 3. Also, sample number P used in setting the load coefficient initial value is 10, the same as that in Application Example 1.

[0112]

As shown in Figure 8, from the distribution of the output signal average power of the multi-beam former, the selected auxiliary beam numbers near the first maximum point are #7, #6, #8, and the selected auxiliary beam numbers near the second maximum point are #51, #52. Also, the order in these cases is not critical. The number of selected auxiliary beams is B=5.

[0113]

Then, matrix A represented by Numeric Formula 7 is formed, and, as shown in Numeric Formula 15, singular value decomposition is performed. The values of the diagonal elements of matrix S are listed sequentially as follows from the (1, 1) element to the (5, 5) element:

351.9 191.7 82.2 0.116

0.051. Among them, the former three singular values are much larger than the 4^{th} and 5^{th} singular values. Consequently, it is judged that the number of incident interference waves is 3. Here, however, it is impossible to judge which and how many incident directions there are in this case by means of the aforementioned operation.

[0114]

Vector α of Numeric Formula 16 is computed, and the various elements of vector c shown in following Numeric Formula 19 are computed.

[0115]

[Numeric Formula 19]

$$[c]_i = \begin{cases} [\alpha]_i / [S]_{ii} & i = 1,2,3 \\ 0 & i = 4,5 \end{cases}$$

[0116]

Then, by means of Numeric Formula 18, the load initial value is computed. Here, the value is taken as the load coefficient initial value, and, in the same way as in Application Example 1, the load coefficient is refreshed. In this case, Figure 10 shows the degree of improvement (improvement factor in units of dB) of the signal-to-noise ratio for the interference signal versus the number of rounds of refreshing of the load coefficient. Also, Figure 10 shows the convergence characteristics when the method described in Reference 1 is used and the load coefficient initial value is taken as the 0 vector. In both cases, the selected auxiliary beams are the same five auxiliary beams, that is, #7, #6, #8, #51, #52.

[0117]

In the procedure for setting the load coefficient initial value in the present application example, too, it is believed that the operation does not come to an end until input of the next sample, and time is required corresponding to about several tens of samples. However, as can be seen from Figure 10, even when this fact is taken into consideration, the load coefficient still converges in a very short time. Also, it can be seen that even if the signal selection number in selector (8) exceeds the number of the interference waves, convergence is still quick.

[0118]

Effects of the invention

As explained above, according to the present invention, based on a prescribed number of signals selected as auxiliary beams from plural signals corresponding to multiple beams and signals corresponding to beams in a prescribed direction, the initial value of the load coefficient is set, and auxiliary beams in the same number as that of the received interference waves are selected. As a result, even if two or more interference waves near each other are incident, it is still possible to set the initial value near the optimum value and to have the load coefficient reach the optimum value, and it is possible to realize interference wave suppressing characteristics. This is the effect of the present invention.

[0119]

As another feature of the present invention, based on plural signals corresponding to the multiple beams and the spatial distribution of their average power, the number of interference waves is specified, and signals in a number equal to or larger than the number of interference waves are selected from said plural signals. As a result, even if two or more interference waves near each other arrive, or even if the auxiliary beam width is large, reliable auxiliary beam selection is still possible, and the initial value of the load coefficient can be set near the optimum value.

[0120] /12

As another feature of the present invention, as the adaptive algorithm, for the initially received prescribed number of signal samples, the initial value of the load coefficient is set based on the solution of a set of simultaneous equations based on the signals corresponding to the beams in the prescribed direction and the selected signals in the prescribed number, and the algorithm for refreshing the load coefficient is used. As a result, it is possible to set an initial value that is near the optimum value in a reliable way, and interference wave suppression characteristics can be realized in a short time.

[0121]

According to another feature of the present invention, singular value decomposition is additionally performed for a prescribed matrix from the plural signals corresponding to the multiple beams, and the number of singular values is taken as the number of interference waves. As a result, the initial value of the load coefficient can be near the optimum value, and, at the same time, it is possible to specify the number of interference waves easily.

[0122]

As another feature of the present invention, the initial value of the load coefficient is set based on the solution of a set of simultaneous equations for the initially received prescribed number of signal samples, and, while the load coefficient is refreshed based on the set initial value, an algorithm for setting the initial value such that the load coefficient has the minimum norm of the initial value spectrum is adopted. As a result, interference wave suppression characteristics can be realized in a short time, and in the orientation characteristics after convergence of the load coefficient, the gain other than for the principal beam does not increase.

[0123]

As another feature of the present invention, all or a portion of the plural digital in-phase/orthogonal signals are used to determine the number of interference waves and their incident directions, and, for each incident direction, beams are formed, and, by means of the singular value decomposition method for the initial prescribed number of received signal samples in the auxiliary beam output, even if two or more interference waves near each other are incident, it is still possible to set the initial value near the optimum value. As a result, it is possible for the load coefficient to reach a very high speed, and it is possible to realize interference wave suppression characteristics in a short time. Also, as the initial value obtained using the singular value decomposition method is the minimum norm solution, gain other than for the principal beam in the orientation characteristics after convergence does not increase.

Brief description of the figures

Figure 1 is a block diagram illustrating the constitution of the interference wave suppressor in Embodiment 1 of the present invention.

Figure 2 is a flow chart illustrating a portion of the procedure in setting the selected auxiliary beams by selected beam setter (21a) pertaining to Embodiment 1.

Figure 3 is a flow chart illustrating a portion of the procedure in setting the selected auxiliary beams by selected beam setter (21a) pertaining to Embodiment 1.

Figure 4 is a flow chart illustrating a portion of the procedure in setting the selected auxiliary beams by means of selected beam setter (21a) pertaining to Embodiment 2 of the present invention.

Figure 5 is a flow chart illustrating a portion of the procedure for setting the selected auxiliary beams by selected beam setter (21a) pertaining to Embodiment 2.

Figure 6 is a block diagram illustrating the constitution of the interference wave suppressor pertaining to Embodiment 3 of the present invention.

Figure 7 is a block diagram illustrating the constitution of the interference wave suppressor pertaining to Embodiment 4 of the present invention.

Figure 8 is a diagram illustrating the spatial distribution of the output signal power of the multi-beam former in Application Example 1 of the present invention.

Figure 9 is a diagram illustrating the convergence characteristics of the interference wave suppressor pertaining to Embodiments 1 and 2 in Application Examples 1 and 2.

Figure 10 is a diagram illustrating the converging characteristics of the interference wave suppressor pertaining to Embodiment 3 in Application Example 3.

Figure 11 is a flow chart illustrating the constitution of an interference wave suppressor in the prior art.

Explanation of symbols

1-1-1-N	Antenna element
2-1-2-N	Receiver
3-1-3-N	A/D converter
4-1-4-N	IQ signal converter
5	Beam former
6	Subtractor
7	Multi-beam former
8	Selector
9-1-9-B	Multiplier
10	Adder
11	Fast Fourier transformer
21a, 21b	Selected beam setter
22	Load coefficient controller
23a, 23b, 24	Load coefficient initial value setter
30	Interference wave incident direction determining unit
31-1-31-B	Auxiliary beam former

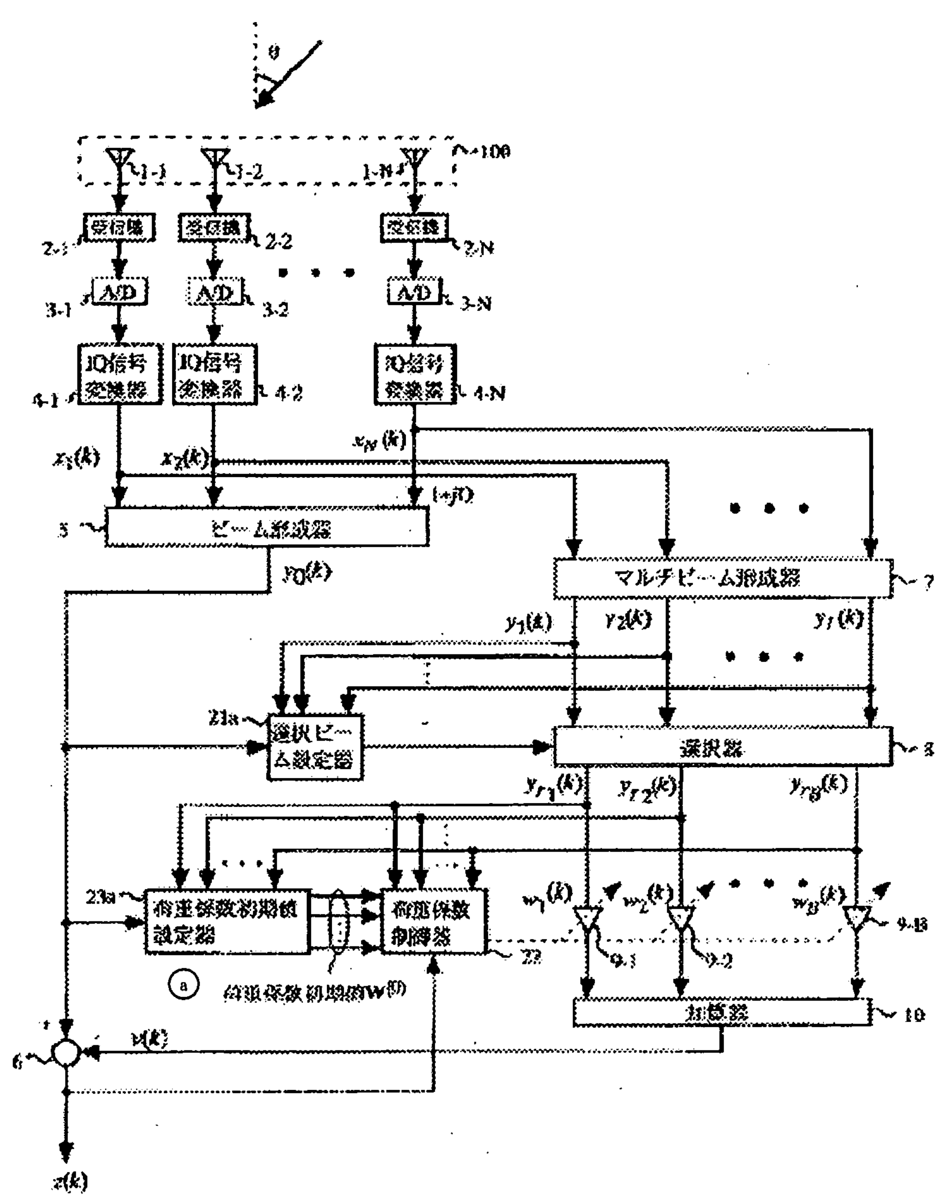

Figure 1

Key:

2-1-2-N	Receiver
4-1-4-N	IQ signal converter
5	Beam former
7	Multi-beam former
8	Selector
10	Adder
21a	Selected beam setter
22	Load coefficient controller
23a	Load coefficient initial value setter
a	Load coefficient initial value $W^{(0)}$

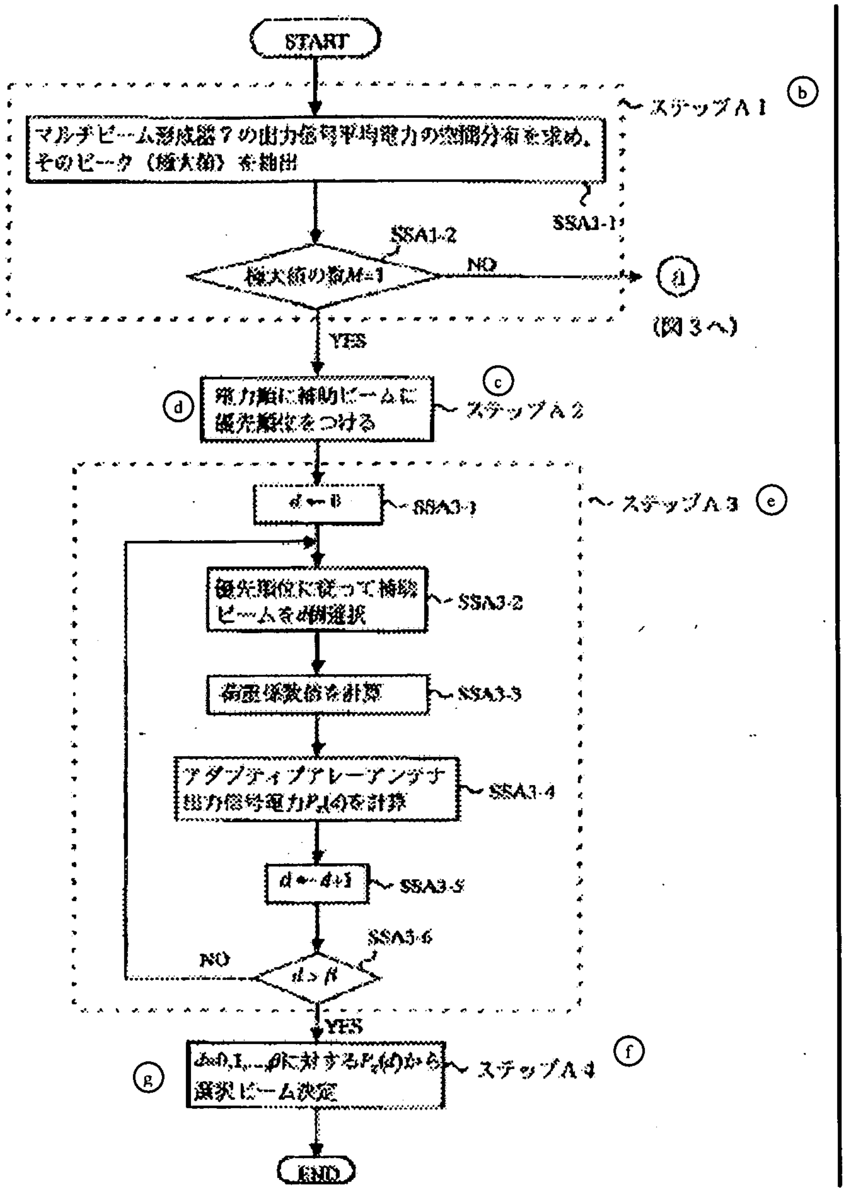

Figure 2

Key:	a	(To Figure 3)
	b	Step A1
	SSA-1-1	Determination of spatial distribution of the output signal average power of multi-beam former (7), and extraction of the peaks (maximum values)
	SSA1-2	Maximum value number M=1?
	c	Step A2
	d	Attachment of priority order to auxiliary beams in the order of electric power
	e	Step A3
	SSA3-2	Selection of d auxiliary beams according to priority order
	SSA3-3	Computing of load coefficient value
	SSA3-4	Computing of adaptive array antenna output signal power $P_z(d)$

	f	Step A4
	g	Determination of selected beams from $P_z(d)$ for $d=0,1,\ldots \beta$

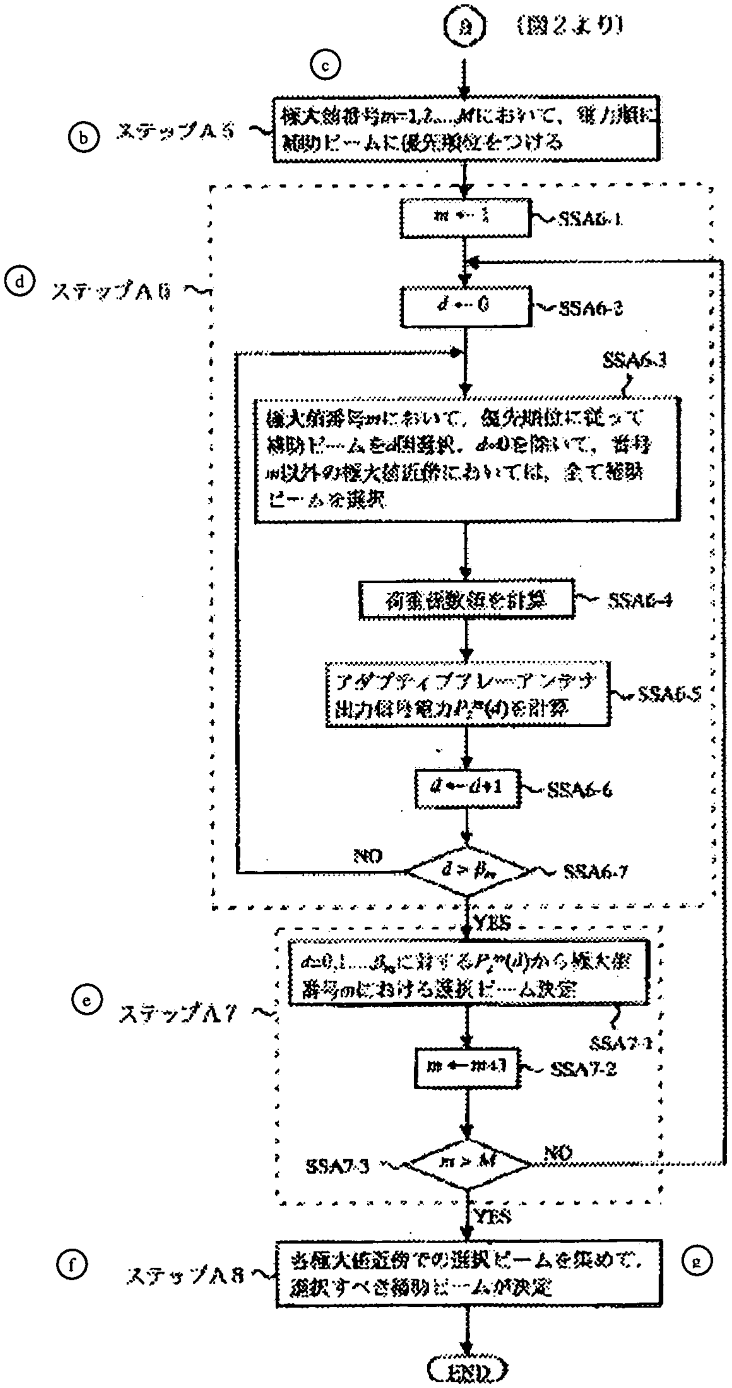

Figure 3

Key:	a	(From Figure 2)
	b	Step A5

c	Attaching of priority order to the auxiliary beams in the order of electric power at maximum value number m=1, 2,... M
d	Step A6
SSA6-3	At maximum value number m, according to the priority order, d auxiliary beams are selected. Near the maximum value other than number m and excluding d=0, all of the auxiliary beams are selected
SSA6-4	Computing of load coefficient value
SSA6-5	Computing of adaptive array antenna output signal power $P_z^m(d)$
e	Step A7
SSA7-1	Determination of selected beams at maximum value number m from $P_z^m(d)$ for d=0, 1,... β_m
f	Step A8
g	Selected beams near each maximum value are collected, and the auxiliary beams that should be selected are determined

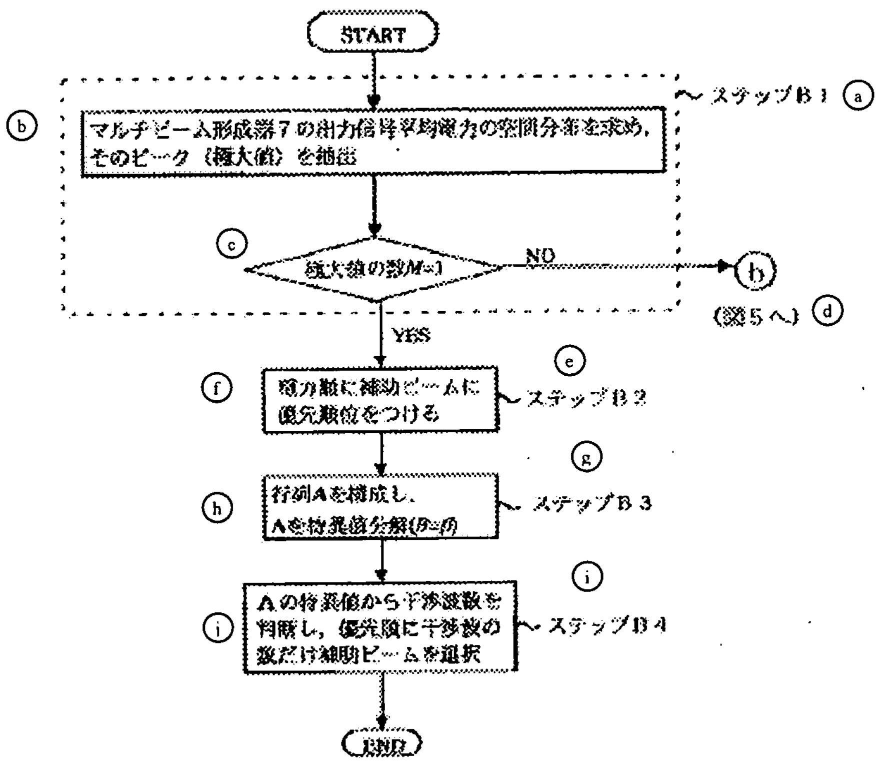

Figure 4

Key:		
	a	Step B1
	b	Determination of spatial distribution of the output signal average power of multi-beam former (7), and extraction of the peaks (maximum values)
	c	Maximum value number M=1
	d	(To Figure 5)
	e	Step B2
	f	Attachment of priority order on the auxiliary beams in the order of electric power

g	Step B3
h	Construction of matrix A, singular value decomposition of A (B=β)
I	Step B4
j	Judgment of the interference wave number from the singular values of A, and selection of the auxiliary beams in the number of the interference waves in priority order

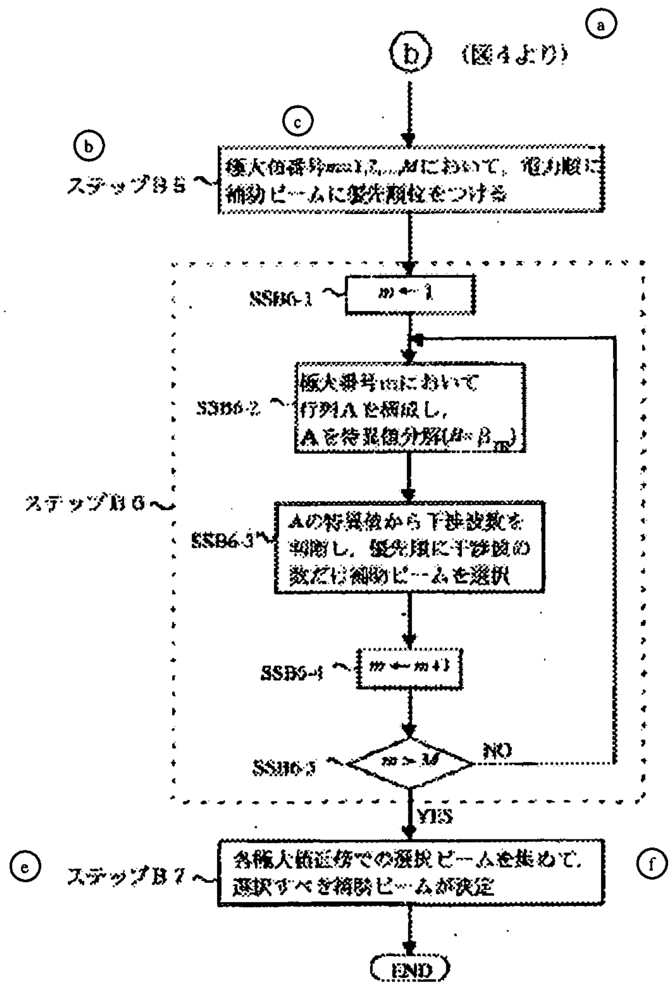

Figure 5

Key:

a	(From Figure 4)
b	Step B5
c	Attachment of priority order to auxiliary beams in the order of electric power for maximum value number m=1, 2,... M
d	Step B6
SSB6-2	At maximum value number m, matrix A is constructed, and A is subjected to singular value decomposition ($B=\beta_m$)

SSB-3	Judgment of interference wave number from singular values of A, and selection of auxiliary beams from only the number of interference waves in the priority order
e	Step B7
f	Collection of selected beams near each maximum value, and determination of the auxiliary beams to be selected

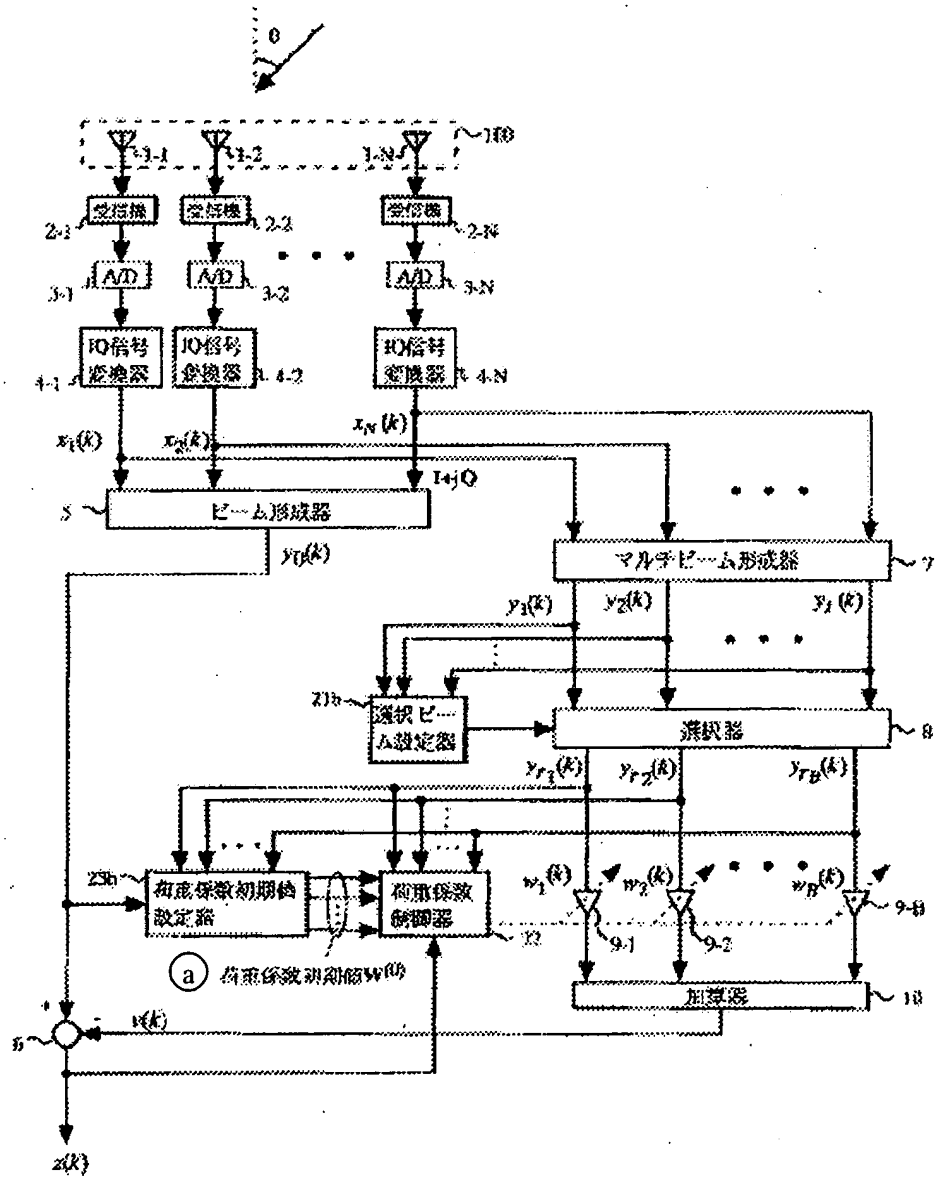

Figure 6

Key:	a	Load coefficient initial value $W^{(0)}$
	2-1-2-N	Receiver
	4-1-4-N	IQ signal converter
	5	Beam former

7	Multi-beam former
8	Selector
10	Adder
21b	Selected beam setter
22	Load coefficient controller
23a	Load coefficient initial value setter

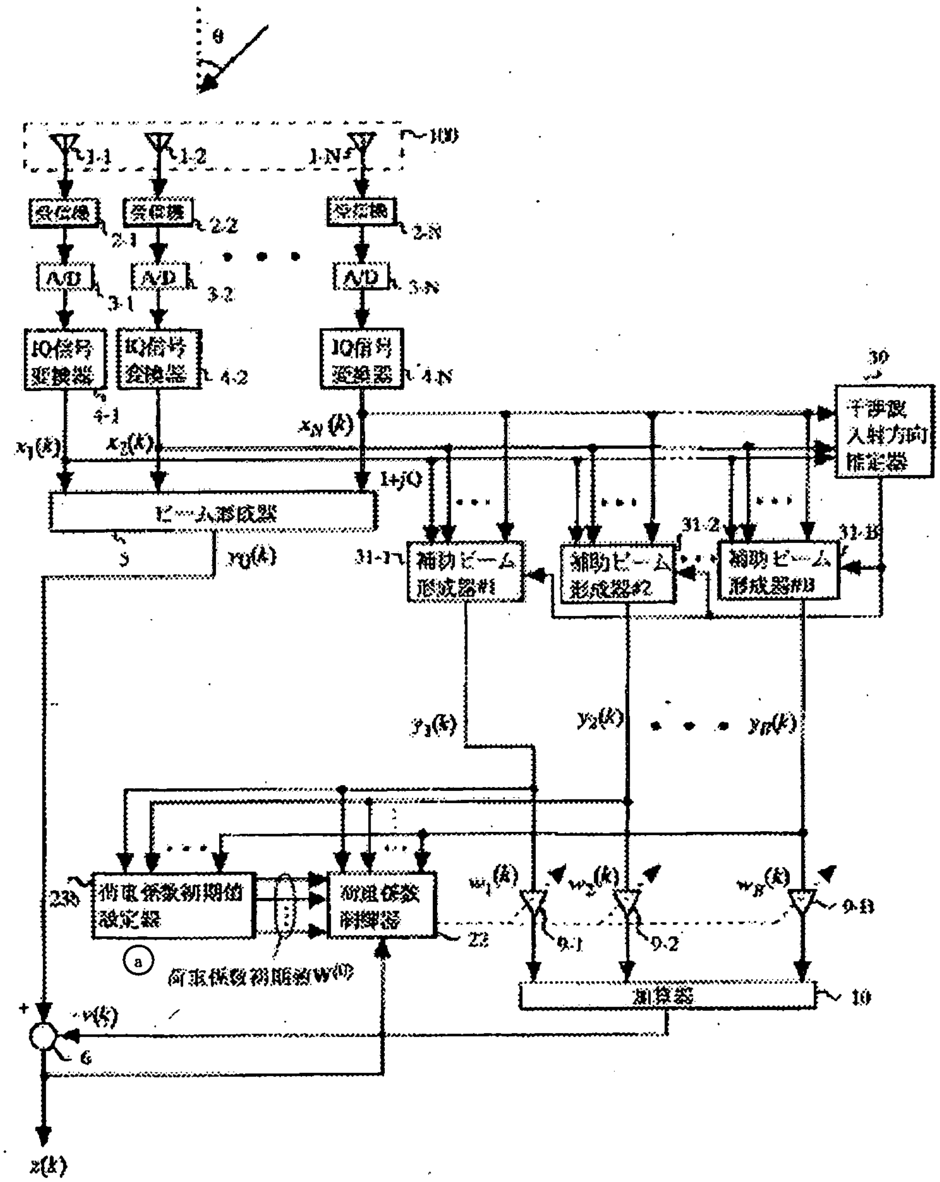

Figure 7

Key:

a	Load coefficient initial value $W^{(0)}$
2-1-2-N	Receiver
4-1-4-N	IQ signal converter
5	Beam former

10	Adder
22	Load coefficient controller
23b	Load coefficient initial value setter
30	Interference wave incident direction determining unit
31-1	Auxiliary beam former #1
31-2	Auxiliary beam former #2
31-B	Auxiliary beam former #B

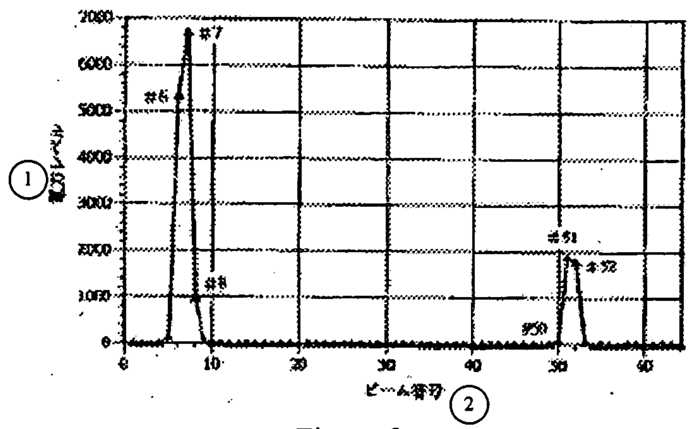

Figure 8

Key:
1 Power level
2 Beam number

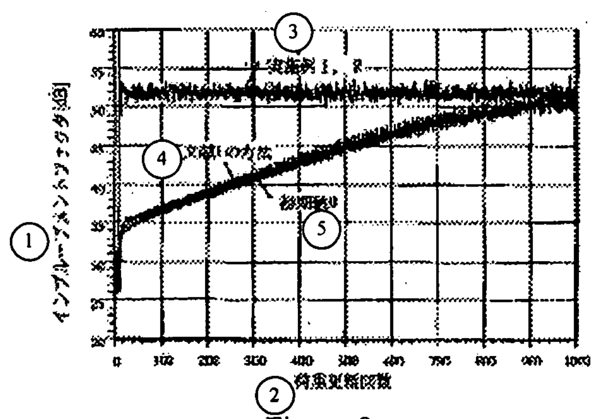

Figure 9

Key:
1 Improvement factor (dB)
2 Number of rounds of refreshing of load
3 Application Examples 1, 2
4 Method of Reference 1
5 Initial value 0

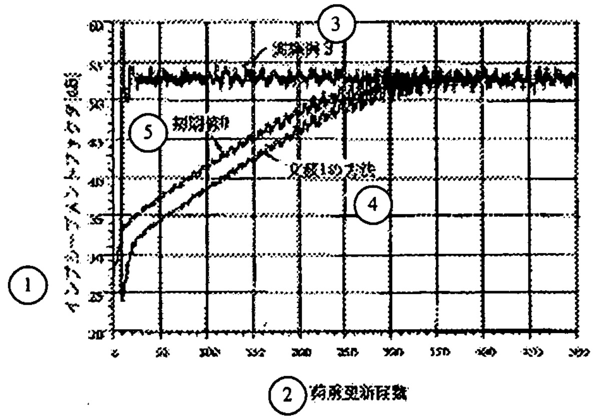

Figure 10

Key:
1 Improvement factor (dB)
2 Number of rounds of refreshing of load
3 Application Examples 1, 2
4 Method of Reference 1
5 Initial value 0

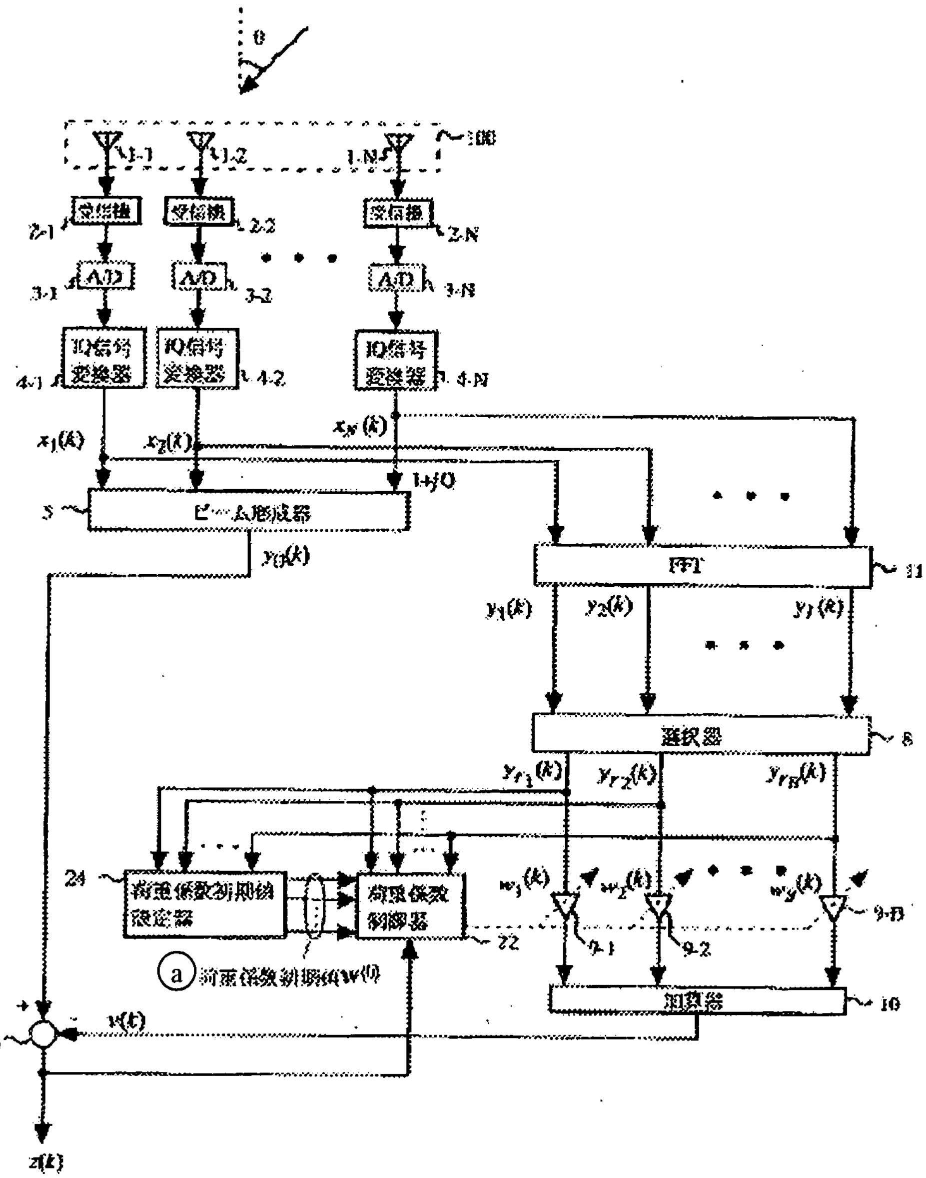

Figure 11

Key:	a	Load coefficient initial value $W^{(0)}$
	2-1-2-N	Receiver
	4-1-4-N	IQ signal converter
	5	Beam former
	8	Selector
	10	Adder
	22	Load coefficient controller
	24	Load coefficient initial value setter